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International Intervention Policy and Nordic Status on Intervention

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Abstract A radiation protection philosophy for exposure situations following an accident has been developed by international organisations such as the ICRP, IAEA, NEA/OECD, FAO/WHO, and the CEC during the last decade. After the Chernobyl accident, the application of radiation protection principles for intervention situations such as exposure from accidental contamination or radon in dwellings were further developed and this work is still in progress. The present intervention policy recommended by the international organisations as well as by the Nordic radiation protection authorities is reviewed. The Nordic Intervention levels for foodstuff restrictions, both for the Chernobyl and post-Chernobyl periods, have been based on dose limits and they are therefore in conflict with international intervention policy. Illustrative examples on intervention level setting for relocation and foodstuff restrictions are derived for Nordic conditions from the optimisation principle recommended by the international organisations. Optimised Generic Intervention Levels have been determined to be about 10 mSv$\cdot$month^{-1} for relocation/return and 5,000$-$30,000 Bq$\cdot$kg^{-1} for restrictions on various foodstuffs contaminated with ^{137}Cs and ^{131}I.

This work has been performed as a part of the Nordic Safety Research Programme (NKS) under the Section “Emergency in abnormal radiation situations” (BER). The purpose of the BER-programme is to evaluate systematically those parts of emergency preparedness that need to be harmonized within the Nordic Countries as a basis for uniform action in emergency situations.

The present report of the NKS-programme BER-3 has been prepared within Risø-project No. 02471-00. The aim of the BER-3 project is to propose and harmonize Nordic Intervention Levels for protective actions in case of a nuclear accident. A part of the project is to review the work of the international organisations on intervention.

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Contents

1 Introduction

After the Chernobyl accident a new thinking in radiation protection principles evolved. The radiation protection philosophy of today as recommended by the ICRP distinguishes between (a) the introduction of a **practice** which causes either actual exposures or probabilities of exposure and therefore will **add** radiation doses to the existing background, and (b) **intervention** situations in which radiation exposures can be reduced only by intervention in order to put exposed people in a better position.

In intervention situations such as the post-Chernobyl situation or radon in dwellings, the radiation sources, pathways, and exposed individuals are already present when the decisions on control measures are being considered. The reduction of radiation doses can therefore be achieved only by **intervention**. The protective measures forming a programme of intervention, which always have some disadvantages, should each be **justified** on its own merit in the sense that it should do more good than harm, and its form, scale, and duration should be **optimised** so as to maximise the net benefit.

The dose limits are intended for use in the control of **practices** and **not for intervention.** The use of these dose limits, or of any other pre-determined dose limits, as the basis for deciding on intervention might involve measures that would be out of all proportion to the benefit obtained and would be in conflict with the principle of justification. Therefore, dose limits must **not** be used for deciding on the need for or scope of intervention. However, at some level of individual dose, which would cause serious deterministic effects, some kind of intervention will become almost always justified.

After the Chernobyl accident the international radiation protection organisations have been engaged in the work of improving the criteria for intervention. The ICRP, IAEA, and NEA/OECD have all been involved in the general philosophy, whereas other organisations only have been working on guidance on foodstuff control.

In order to provide background for the Nordic interpretation of international recommendations of radiation protection philosophy for interventions, the present report reviews the recommendations developed by the ICRP, IAEA, NEA/OECD, WHO/FAO, and CEC for protection of the **public**. The present situation in the Nordic countries is also reviewed. Illustrative examples on the derivation of Intervention Levels from the justification/optimisation principles are elaborated.

The work has been performed as a part of the Nordic BER-3 Project *Evaluation and harmonization of countermeasures and the use of intervention levels.*

2 International Guidance on Intervention at the time of the Chernobyl Accident

General

The Commission of the European Communities (CEC) was the first international body to publish guidance in 1982 to its member states on reference levels of radiation dose as guidance to national authorities in setting intervention levels [11]. Similar guidance was published by the ICRP in 1984 [2], World Health Organization, WHO, in 1984 [8] and International Atomic Energy Agency, IAEA, in 1985 [1].

The guidance given by these four organizations was similar in essence. The WHO guidance was less quantitative; the reference dose levels for sheltering, distribution of stable iodine tablets, and evacuation set forth by CEC differ slightly from those given by ICRP and IAEA; and the CEC did not give any values for control of foodstuffs. The ICRP and IAEA gave almost identical advice.

The basic principles given by ICRP [2] for planning intervention for accident situations and setting intervention levels were the following:

(a) Serious deterministic effects should be avoided by the introduction of countermeasures to limit individual dose to levels below the thresholds for these effects;

(b) The risk from stochastic effects should be limited by introducing countermeasures which achieve a positive net benefit to the individuals involved;

(c) The overall incidence of stochastic effects should be limited, as far as reasonably practicable, by reducing the collective dose equivalent.

It was internationally recognized that the spectrum of accident situations is wide, and that difficulties in implementing protective measures after an accident vary widely from country to country and even from place to place within a country. Therefore, it was not considered possible to set one generally applicable intervention level at which a particular action would always be required.

On the other hand, it was recognized that introduction of protective measures would be almost certain if the projected radiation dose were such that serious deterministic effects or a high probability of stochastic effects would be expected. It was also considered that it would be possible, on radiation protection grounds, to define a level of radiation dose for each countermeasure below which introduction of the countermeasure would not likely be warranted.

Upper dose levels above which introduction of the countermeasure is almost certain and lower dose levels, below which introduction of the countermeasure is not warranted were given for whole body irradiation and also for individual organs. Between the recommended upper and lower levels site-specific intervention levels were expected to be set by national authorities. The intervention levels covered both early and intermediate phases. For the late phase no values were recommended, since it was considered that the main questions facing the decision maker would be whether and when normal living could be resumed, and the situations would vary too widely to give any generic numbers for that purpose.

The numerical values of the intervention levels recommended by the IAEA [1] and ICRP [2] for the first year after the accident are summarised in Table 1.

Table 1. *ICRP intervention level ranges for introducing countermeasures*

Countermeasure	Dose levels	
	Whole body	Single organs
Sheltering	5 – 50 mSv	50 – 500 mSv
Stable iodine	–	50 – 500 mSv
Evacuation	50 – 500 mSv	500 – 5000 mSv
Relocation	50 – 500 mSv/a	not anticipated
Control of foodstuffs	5 – 50 mSv/a	50 – 500 mSv/a

The projected dose per year for relocation and foodstuff control are defined only for the first year.

Main problems in the earlier recommendations
In regard to international guidance on intervention levels a number of problems were identified when it was applied to the Chernobyl accident, although its basic principles were still considered to be valid. The major difficulties in its application were:

- how to apply intervention levels. For example, in the case of food, did the intervention level refer to the sum of the food items or to each of them separately?
- how to compare the dose with the intervention level. Was the projected dose or the avertable dose relevant?
- how was the principle (c) to be applied? What was the relationship between principles (b) and (c)?

Major confusion was also created by the references in the ICRP publication [2] to the dose limits in justifying the numerical values of the intervention levels.

3 The International Commission on Radiological Protection

3.1 ICRP Publication 60

In the new general radiation protection recommendations from the ICRP [6], a generalized description is given of the system of radiation protection in **existing** exposure situations such as radon in dwellings and (post) accident/emergency situations.

Basic Principles
In existing exposure situations, i.e. existing at the time when control procedures are being considered, the choice of action is limited. The most effective action, that applied at the source, is rarely available and controls have to be applied in the form of intervention.

The system of radiological protection for intervention is based on the following general principles:

(a) The proposed intervention should do more good than harm, i.e. the reduction in detriment resulting from the reduction in dose should be sufficient to justify the harm and the costs, including social costs, of the intervention.

(b) The form, scale, and duration of the intervention should be optimised so that the net benefit of the reduction of dose, i.e. the benefit of the reduction in radiation detriment, less the detriment associated with the intervention, should be maximised.

Dose limits do not apply in the case of intervention. Principles (a) and (b) can lead to intervention levels which provide guidance to those situations in which intervention is appropriate. Because of serious deterministic effects, there will be some level of projected dose above which intervention will almost always be justified. The process of justification and optimisation **both** apply to the protective action, so it is necessary to consider them **together** when reaching a decision.

Justification is the process of deciding that the disadvantages of each component of intervention, i.e. of each protective action or, in the case of accidents, each countermeasure, are more than offset by the reductions in the dose likely to be achieved. **Optimization** is the process of deciding on the method, scale, and duration of the action so as to obtain the **maximum net benefit.** In simple terms, the difference between the disadvantages and the benefits, expressed in the same terms, e.g. monetary terms, should be positive for each countermeasure adopted and should be **maximized** by setting the details of that countermeasure.

The cost of intervention is not expressed solely in terms of monetary cost. Some remedial actions may involve non-radiological risks or serious social impacts. For example, the short-term removal of people from their homes is not very expensive, but it may cause the temporary separation of members of a family and result in considerable anxiety. Prolonged evacuation and permanent relocation are both expensive and traumatic.

Application of principles

Because the initial introduction of protective actions on any scale, however small, involves significant costs, it may well be that small-scale, short duration intervention is costly without being effective. As the proposed scale and duration are increased, the effectiveness initially increases without a marked increase in costs, so the net benefit may become positive. Eventually, further increases will fail to achieve increased benefits comparable with their costs, and the net benefit again becomes negative. There is then a **range of values** of the possible intervention level of individual dose **averted**, within which there is an optimum level. If the net benefit at that optimum is **positive,** intervention of the defined type, scale, and duration will be **justified.**

The benefit of a particular countermeasure within a programme of intervention should be judged on the basis of the reduction in dose achieved or expected by that special protective action, the dose **averted.** Thus, **each** protective action has to be considered on its **own** merits. For example, decisions about the control of individual foodstuffs are independent of those made about other foodstuffs, and about sheltering and evacuation. In addition, however, the doses that would be incurred via **all** the relevant pathway of exposure, some subject to protective actions and some not, should be assessed. If the total dose to some individuals is so high as to be unacceptable in any circumstances, the feasibility of additional countermeasures influencing the major contributions to the total dose should be urgently reviewed. Doses causing **serious deterministic effects** or a **very high** probability of stochastic effects would call for such a review.

3.2 ICRP Publication 40 Revision 1

The revision of the Publication 40 was adopted by the Commission in November 1992 [3]. The following aspects are stressed when applying the basic principles of intervention introduced in Publication 60.

The first concern in the event of a radiological emergency is to keep the exposure to individuals from all pathways below the thresholds for serious deterministic health effects. In addition to preventing serious deterministic effects, the unacceptability of a high risk of stochastic health effects to individuals may be a significant factor in the decision making process. In this case, the justification of the protective action from the individual's point of view may become the dominant factor. In fact, when deciding on the implementation of protective actions, the decision maker should first determine whether the protective action is justified from the viewpoint of those individuals who are at most risk.

After that, consideration should be given to justifying the action from the viewpoint of society, since the costs and benefits will probably not be evenly distributed amongst the same people. The societal considerations may extend the protective action to cover an even larger group of affected people, or they may set limits to the practical or financial feasibility of the action (e.g. evacuation of a large city). In case the proposed protective action is not justified from the viewpoint of the individuals, decision makers may still seek to reduce the collective dose and hence the detriment from the emergency, and care should be taken **not** to do more harm than good.

Justification of an intervention should begin by considering the average avertable individual dose for the whole of the exposed population to which the intervention would be applied (e.g. sheltering, evacuation, relocation). In some cases the avertable collective dose can be used when the exposed population is not easily identified (e.g. food restrictions, decontamination). If implementation of the protective action is not justified, consideration should be given as to whether there are subgroups of the population whose characteristics differ significantly from the average and for whom the protective action might be justified (e.g. by greater doses to be averted or lesser costs). These include pregnant women and small children, hospitalized or other institutionalized individuals. Separate optimisation is needed for workers engaged in the protective measures and social and psychological costs should be considered when different population groups are treated differently.

Political and wider social factors will necessarily be a part of decision making following radiological emergencies. The competent authorities responsible for radiation protection should therefore be prepared to provide the radiation protection input (justification and optimisation of the protective actions on radiological grounds) to the decision making process in a systematic manner, indicating all the radiological factors already considered in the analysis of the protection strategy. In the decision process the radiological protection and the political factors should each be taken into account only once to avoid the introduction of the same political factors in several places.

Table 2. Summary of Recommended Intervention Levels (ILs) from the ICRP.

Intervention Levels of averted dose or averted activity concentration		
Protective measure	Almost always justified	Range of optimum values
Sheltering (< 1 day)	50 (a)	5 – 50 (a)
Administration of stable iodine	500 (b)	50 – 500 (b)
Evacuation (< 1 week)	500 (a) 5,000 (c)	50 – 500 (a) 500 – 5,000 (c)
Restriction on a single foodstuff	10 mSv in a year (d)	1,000 – 10,000 Bq·kg^{-1} (β-emitters) 10 – 100 Bq·kg^{-1} (α-emitters)
Relocation	1,000 (a)	5 – 25 mSv per month (a)

(a) is averted effective dose
(b) is averted equivalent dose to thyroid
(c) is averted equivalent dose to skin
(d) is averted effective dose committed in a year

It is of great importance, however, that decision makers inform the public of all aspects of their decisions, especially when the interventions are chosen mainly for political, social, and/or economic reasons, rather than on health protection grounds.

Otherwise the public may be misled and the radiological protection efforts will be mistrusted.

The recommended Intervention Levels from the ICRP in Publication 40, Revision 1 are summarised in Table 2 [3].

4 The International Atomic Energy Agency

4.1 IAEA Safety Series No. 72 Revision 1

The IAEA has prepared a revised Safety Guide, “Radiological Protection Principles for Sources not under Control: Their Application to Accidents” [4], which is intended to supersede the Safety Series No. 72. It explains in more detail the situations in which some aspects of the normal system of radiological protection do **not** apply in accident situations, and describes the principles to be used in these situations. This guide, however, is **not** intended to provide a selection of numbers that can be conveniently adopted by responsible authorities for their emergency plans but rather to encourage the authorities to generate their emergency plans with the basic principles as their foundation.

In order to apply the system of radiological protection to existing sources the basic principles were restated concerning the interventions affecting the members of the public, as follows [4]:

(1) The intervention should be **justified** in the sense that introduction of the protective measure should achieve more good than harm.

(2) The level at which the intervention is introduced, and the level at which it is later withdrawn, should be **optimised** so that it will produce the maximum net benefit.

(3) All possible efforts should be made to prevent serious deterministic health effects by restricting doses to individuals to levels below the threshold for such effects.

The first two principles each require, according to the IAEA, consideration of the benefit that would be achieved by the intervention and the harm, in its broadest sense, that would also result from it. They therefore require the use of the procedures for reaching decisions. The inputs to justification and optimisation studies include factors that are related to radiological protection, whereas the final decisions may also depend on other factors, probably of a political nature. Radiological factors are defined as those which are related to the level of protection achieved. Thus they include factors describing the doses **averted** and those describing the costs and other disadvantages incurred in averting the doses.

IAEA has considered the following factors to be clearly radiological protection factors which are more or less quantifiable:

- the avertable individual and collective risks from exposure to radiation for the members of the public
- the individual and collective physical risks to the public caused by the countermeasure
- the individual and collective risks to the workers in carrying out the countermeasure
- the monetary cost of the countermeasure

- reassurance of the public and the workers provided by the implementation of the countermeasure
- anxiety caused by the implementation of the countermeasure
- individual and social disruption caused by the implementation of the countermeasure

Although the two principles of justification and optimisation are stated separately and are indeed conceptually separate, it is necessary to consider them together when reaching a decision. The general case is likely to be that there is a range of optimised values of the intervention level for different scenarios that give more good than harm, so that the intervention is then justified over this range of levels, with the selection of the most appropriate level depending on the particular circumstances.

The characteristics of accident sequences postulated for a nuclear installation, the local environmental conditions and national or regional considerations may all influence the choice of intervention levels. Clearly, to be most appropriate, intervention levels should be developed specifically for the circumstances of interest. This need for specificity and the potential variability of intervention levels depending on the prevailing circumstances inhibit the degree to which quantitative guidance can be established that will be broadly (internationally) applicable.

However, IAEA has provided **indicative** guidance that may be used as an aid to national authorities in establishing their own particular levels. Such guidance is given in Table 3 for the five major protective measures: sheltering, issue of stable iodine, evacuation, relocation, and food restrictions. For each protective measure an intervention level range is given. The indicative nature of the guidance must be emphasized and it must **not** be taken to preclude intervention levels **outside** the specified ranges. It would, however, be erroneous to select arbitrarily values from the bottom of the range in preference to others on the grounds that this is cautious and would therefore lead to the best outcome.

Table 3. *IAEA indicative guidance on Intervention Levels* [(a)].

Protective Measure	Quantity [(b)] effective dose	Whole body dose	Thyroid dose
Sheltering	External plus committed doses from intakes (mSv)	About a few to a few tens of mSv	
Administration of stable iodine	Committed doses from intakes (mSv)	-	About a few tens to a few hundred mSv
Evacuation	External plus committed doses from intakes (mSv)	About ten to a few hundred mSv	
Relocation [(c)]	External plus committed doses from intake over a year (mSv)	About a few to a hundred mSv [(d)]	
Food control [(e)]	Committed doses from intakes in a year (mSv)	About one to a few tens of mSv	

(a) This quantitative guidance is indicative only. The ranges of values should not be adopted for application without first analysing carefully their appropriateness to the particular circumstances of interest.

(b) This is the quantity to be compared with the intervention level. In principle it is the dose averted that is to be compared but in practice this can often be equated with the projected dose.

(c) A somewhat wider range of levels is quoted for relocation compared with the other protective measures. This is intended to reflect the greater sensitivity of this measure to the magnitude of the accident.

(d) In some cases, this criterion can also be expressed in terms of dose rate. In these circumstances the indicative guidance for dose rate is in the range of one to a few tens of μSv/h.

(e) This applies separately to each of the following categories of foodstuffs: dairy products, meats, vegetables, grain, fruit, drinking water and beverages.

It should be emphasized that the ranges given in Table 3 should **not** be considered as the two–tier system recommended earlier by practically all the international organisations. The ranges should, on the other hand, be considered as comprising the optimum intervention levels that would be achievable in practice depending on the accidental and site specific circumstances.

Intervention levels are specified in terms of **averted dose**. In practice, however, the results of environmental measurements will be expressed in terms of dose rates and concentrations (e.g. mSv/h, Bq/m^3, Bq/m^2). In order to interpret these measurements in terms of intervention levels of dose, it is convenient to calculate in advance **operational intervention levels** (OILs) which correspond, under specified conditions, to intervention levels. These operational intervention levels are expressed in the same quantities and units as the environmental measurements. The principles and procedures for deriving numerical values of the OILs have been published by the IAEA as part of its programme of Safety Series publications in the Safety Series No. 81, "Derived Intervention Levels for Application in Controlling Radiation Doses to the Public in the Event of a Nuclear Accident or Radiological Emergency" [5] which is presently under revision.

In practice, intervention levels can in many cases be derived in easily measurable quantities directly as a result of the optimisation process (see Annex B and C).

4.2 IAEA Safety Series No. 81 Revision 1

At present, a revision of Safety Series No. 81 [5] is undertaken by the IAEA. The major change will be that the revised document will be a general document on intervention levels and not specifically on derived intervention levels. The recommended intervention levels would be based on the justification/optimisation principles. ILs will be given for both urgent and later countermeasures. Publication of the revised report in the Safety Series is planned for in 1993.

Table 4. IAEA Intervention Levels (ILs) for control of foodstuffs (Bq/kg).

Radionuclide	Fresh milk, Vegetables, Grain, Fruit	Meat, Milk Products
^{106}Ru, ^{131}I, ^{134}Cs, ^{137}Cs	3,000	30,000
^{90}Sr	300	3,000
^{238}Pu, ^{239}Pu, ^{241}Am	30	300

Intervention levels are given for the protective measures of sheltering, administration of stable iodine, evacuation, control of foodstuffs, and relocation. Preliminary values of ILs for foodstuff control are shown in Table 4.

For relocation, a distinction is made between **temporary** and **permanent** relocation. Temporary relocation is the removal of people for an extended but limited period of time, and permanent relocation is a removal of people with no expectation of return within their lifetime. Preliminary values of ILs for temporary and permanent relocation as well as for sheltering, evacuation, and thyroid blocking are shown in Table 5.

Table 5. IAEA Intervention Levels (ILs) for sheltering, evacuation, thyroid blocking and relocation.

Protective measure	Intervention Level
Sheltering	3 mSv/6 h
Evacuation	10 mSv/day
Stable iodine	50 mGy (infants) 500 mGy (adults)
Temporary relocation	30 mSv in first month 10 mSv/month in subsequent months
Permanent relocation	1 Sv

5 The Nuclear Energy Agency

In the 1990 the NEA/OECD published a report [7] that outlines the status of relevant international activities on intervention principles, discusses these principles, and describes the proposed accident management system together with a general scheme for its application. The principles and criteria for intervention presented in the report, although developed with specific reference to reactor accidents, apply equally well to activities and possible accidents at other nuclear facilities. The report describes briefly the transition from an "accident management" situation back to a "normal" situation and the related problem of changing criteria for the protection of the public.

Basic Principles

The basic principles of the system for accident management as prescribed by the NEA are given below:

(a) any intervention should be **justified,** that is, the introduction of a protective measure should achieve more good than harm;

(b) the level at which an intervention is introduced, and the level at which it is later withdrawn, should be **optimised** so that it will produce the **maximum** good;

(c) the doses to individuals should not exceed levels judged as **unacceptable.**

These principles are seen as generally applicable to all situations and in all circumstances, irrespective of time and distance from the source of the accident.

Application of principles
In the assessment of the radiological impact of an accident from a given exposure pathway, the dose which results from a calculation is usually the **average individual projected dose** committed in the group of people primarily affected by that pathway (reference group). Therefore, it is appropriate, in practice, to express the IL as a projected dose (rather than an averted dose) in order to make it possible to compare the projected doses from calculations directly with the corresponding intervention level. This can be done by introducing the concept of **efficiency** of a protective measure.

In the management of accidents, there are two distinct phases in which optimisation of the protective measures should be considered: In the phase of planning for countermeasures and in the phase of actually encountering them.

In the planning phase, a **generic** optimisation of the protective measures should be studied, based on generic accident scenario calculations. The result of these studies should result, for each protective measure, in optimised generic ILs to be used immediately after an accident and for a short time later.

In a real accident situation, a more precise and **specific** optimisation process, based on real data, should be carried out and should result in **specific** ILs for each protective measure to be used in the longer time period after the accident. It should be emphasized that the search for the best strategy of countermeasures is primarily applicable to the phase of **specific** optimisation.

Individual dose boundaries
If a given group of people were exposed to several independent pathways the total dose from the different pathways might be judged as unacceptable. This may require the introduction of an Upper Boundary (UB) of the total individual dose which should not be exceeded, if and as feasible, irrespective of the result of the justification and optimisation procedures. The establishment of values for the UB is a matter of judgement by national authorities. However, in order to limit the possible diversity of such values between member countries, it would be appropriate to reach an international consensus on the establishment of the UB and, possibly, on a unified value of an Overall Upper Boundary (OUB). The values suggested are a whole body dose of 0.5 Gy committed in a short time and an accumulated effective dose of 0.3−0.5 Sv in the long term.

In some cases, the projected average individual dose from a given pathway is so low that even the application of the justification and optimisation process is not warranted on pure radiological grounds. It appears, therefore, appropriate to establish for each exposure pathway a Lower Boundary (LB) below which protective actions are unlikely to be justified. To limit unnecessary discrepancies between member countries, efforts should be made to reach an international consensus on the establishment of the LB and, possibly, on an unified value of a Minimum Lower Boundary (MLB), which is suggested to be in range of 0.1−1 mSv committed in the first year after the accident.

6 World Health Organisation

After the Chernobyl accident it was recognized that the available guidelines on the management of the consequences of a nuclear accident did not adequately cover the actions to be taken to protect the population in areas far from the accident site.

Therefore, WHO has, in close consultation with CEC, IAEA, and OECD/NEA, developed guidelines [9] to assist national authorities in making decisions on the control of food in the event of widespread contamination by radionuclides from a major nuclear accident.

An Intervention Level of individual dose of **5 mSv/a** has been recommended as justified by comparison with the variation of the natural background radiation that expose the whole body. The total radiation doses from the background exposure lie between 1 and 10 mSv/a. An Intervention Level of 5 mSv/a is therefore comparable with the global variation of the effective dose due to natural radiation sources.

The value of the Derived Intervention Level (DIL) for a category of food varies inversely with the mass consumed, m, and the committed effective dose per unit activity intake, $e(50)$, and directly with the Reference Level of Dose (Intervention Level), RLD:

$$DIL = \frac{RLD}{m \cdot e(50)} \tag{1}$$

The guidelines values for the DILs have been calculated for seven food categories and for drinking water. The calculated values are based on an effective dose of 5 mSv/a for each nuclide **in isolation in a single food category**, since it is not possible to generalise regarding which nuclides will be most important in each food category after an accident. The calculations have been made for radionuclides with both a high and low dose per unit intake. These values are shown in Table 6 [9].

Table 6. WHO guideline values for Derived Intervention Levels (Bq/kg).

Nuclides	Cereals	Roots	Vegetables	Fruit	Meat	Milk	Fish	Water
Low dose Factor	3,500	5,000	8,000	7,000	10,000	4,500	35,000	700
High dose Factor	35	50	80	70	100	45	350	7

The DILs shown in Table 6 have been calculated from a **normalized hypothetical** diet of a total consumption rate of 550 kg/a based on representative values of **higher-than-average consumptions** of different food components in different parts of the world. The radionuclides that can be represented by a high dose factor are ^{239}Pu and other actinides. The radionuclides with a low dose factor are ^{137}Cs, ^{134}Cs, ^{131}I and all other β-/γ-emitting radionuclides of interest.

7 Codex Alimentarius Commission

In the 1989 the Codex Alimentarius Commission published a set of joint FAO/WHO recommendations [10] to control foods in international trade that have been accidentally contaminated with radionuclides. The goal was to provide a system that can be uniformly and simply applied by government authorities and yet one that achieves a level of public health protection to the individual that is **more than adequate** in the event of a nuclear accident.

The joint FAO/WHO Codex Alimentarius Commission (CAC) has based its recommendations on a **reference level** of dose of 5 mSv/a and a **total average**

consumption rate of food of 550 kg/a all of which is assumed to be contaminated. The CAC has adopted guideline values of radionuclide contamination in food below which the foodstuffs are acceptable for international trade without restrictions. The CAC values are shown in Table 7.

Table 7. CAC guideline values for radionuclides in food moving in international trade.

Radionuclides	Activity concentration (Bq/kg)
^{239}Pu and other actinides in milk and infant food	1
^{239}Pu and other actinides in other food	10
^{90}Sr in milk and infant food	100
^{90}Sr in other food	1000
^{131}I, ^{134}Cs, ^{137}Cs and other nuclides	1000

The levels in Table 7 are based on very conservative assumptions and are intended to be used as values below which **no food control restrictions** need be applied in international trade. Measured values above these levels are **not** necessarily of public health concern, but should alert the competent food control authorities for the need to assess the potential health detriment.

The values were developed for ease of application in **international trade** and mean that when the guideline levels are exceeded governments should decide whether and under what circumstances the food should be distributed within their territory or jurisdiction. The values are **not** influenced by optimisation and can be regarded as being **below regulatory concern**.

8 Commission of the European Communities

After the Chernobyl accident the CEC established a set of Derived Reference Levels (DRLs) for control of foodstuffs [12, 13]. At present, the Article 31 Group of Experts is preparing guidelines for introduction of relocation.

8.1 Derived Reference Levels for Foodstuffs

According to the Report by the Article 31 Group of Experts, it is **not** appropriate to set firm limits in dealing with emergency situations because an emergency is rarely, if ever, susceptible to rigid limitation [12]. It is, however, very useful to establish **Reference Levels** below which action is likely to be inappropriate and above which **intervention** ought to be either taken, or at least seriously considered. The Reference Level must be related to the severity and complexity of the intervention action. Simple actions, with few social consequences, are appropriate at low levels of radiation exposure. Complex actions, on the other hand, require high levels of exposure before they can be justified.

The Group of Experts recommended the adoption of two Reference Levels (RLs) - **a lower RL** below which action is extremely unlikely to be justified on radiological protection grounds and **an upper RL** at which action is almost certain to have been attempted on radiological protection grounds. Between the two levels there is scope for judgement.

For the first year after an accident, a lower RL of **5 mSv** was recommended for the committed effective dose equivalent to an age of 70 years from the consumption of foodstuffs [12]. The upper RL was recommended to be **50 mSv.** For iodine isotopes the lower and upper RLs were recommended to be **50 mSv** and **500 mSv** to the thyroid, respectively. For subsequent years, the RLs should be reduced by a factor of 5, i.e. to **1 mSv** and **10 mSv,** respectively. No RLs for the thyroid are needed in the later years because the relevant iodine isotopes all have short half-lives.

For the long-term control of foodstuffs the term **Derived Reference Level (DRL)** has been used in the recommendations [12]. It is **not** a limit and certainly not a tolerance limit or a tolerance level, nor should it be directly used in regulations. It is a **guide** for administrative action for the competent authorities in the process of **optimisation.** In principle, each foodstuff should have a different DRL for each nuclide, and a calculation should be carried out on each occasion and for each location, depending on the activity level in all the relevant foodstuffs for all the relevant nuclides.

As a basis for Community action, the Group of Experts did instead establish interim proposals for the **major components** of diet for three classes of radionuclides, with the conservative assumption that an individual's intake would be equivalent to the consumption of 10 % of the relevant dietary component, uniformly contaminated to the **full value** of the DRL, for **an entire year.** This factor was included in the computations and provides the conservatism needed to make it unnecessary to consider the separate foodstuffs jointly. They can be treated independently. Each food group and each group of nuclides can thus be treated separately from all the others - no allowance need be made for the existence of several contaminated foodstuffs or of nuclides in more than one group. In Table 8 the recommended DRLs are shown for future accidents [12]. These values are all based on the lower RL mentioned above.

Table 8. CEC Derived Reference Levels (Bq/kg) (DRL) for the control of foodstuffs following an accident.

Radionuclides	Dairy products		Major foodstuffs		Drinking water	
	1st year	later years	1st year	later years	1st year	later years
Cesium	20,000	4,000	30,000	5,000	4,000	700
Iodine, strontium	700	500	7,000	3,000	500	400
Plutonium	80	20	400	80	60	10

For minor foodstuffs, e.g. those with an annual consumption of less than about 10 kg, values of **10 times** those for major foodstuffs will be appropriate.

Due to **political considerations** the Commission did not adopt the proposals from the Article 31 Group of Experts but reduced the DRLs by a factor 4 or more. The recommended values from the Commission are shown in Table 9 [13].

If the Commission receives official information on a nuclear accident substantiating that the maximum permissible levels in Table 9 are likely to be reached or have been reached, it will immediately adopt a regulation rendering those maximum permissible levels. The period of validity of this regulation shall not exceed **three months**. After consultation with experts, which shall include the Article

31 Group of Experts, the Commission shall submit to the Council a proposal for adoption or confirmation of this regulation within one month of its adoption.

Table 9. *CEC Maximum Permissible Levels (Bq/kg) (MPL) for radionuclides in foodstuffs for future accidents.*

Radionuclides	Baby foods	Dairy products	Other products	Liquid food
Cesium	400	1,000	1,250	1,000
Iodine	150	500	2,000	500
Strontium	75	125	750	125
Plutonium	1	20	80	20

8.2 Intervention Levels for relocation

At present, a subgroup within the Article 31 Group of Experts is preparing a guide for setting Intervention Levels for relocation. Relocation was not addressed in the former CEC-criteria for intervention [11]. Publication of the guidelines is planned for in 1993. The influence of factors other than dose reduction and monetary costs will be addressed in this publication.

When only averted doses and monetary costs of relocation are included in the generic optimisation the ILs for relocation shown in Table 10 will appear.

Table 10. *CEC Intervention Levels (ILs) for relocation.*

Protective measure	Intervention Level
Temporary relocation	10 mSv/month
Permanent relocation	1 Sv

9 Nordic Countries

9.1 Response to the Chernobyl accident

The five Nordic countries represent together the whole spectrum of fall-out contamination densities in the European countries, from the lowest to the highest contamination levels outside the former USSR. The recommended Intervention Levels for foodstuff restrictions were also different as summarised below.

9.1.1 Denmark

Before the Chernobyl accident no Intervention Levels for foodstuffs existed in Denmark. In the weeks and months after the accident several activity limits for different foodstuffs were set by the authorities. All these levels were derived from dose limits and were accordingly presented as limits.

For ^{131}I the dose limit was set for a one-year-old child at **50 mSv/a** to the thyroid, and the corresponding activity limits in milk and leafy vegetables were set at **500 Bq/ℓ** and **1000 Bq/kg**, respectively.

For the exposure from intakes of activities of the radioisotopes ^{137}Cs and ^{134}Cs the dose limit was set at **0.5 mSv/a**. Assuming a ^{134}Cs/^{137}Cs activity ratio of 1:2 in foodstuffs, the corresponding activity limit was set at **500 Bq/kg**. This value was used until the end of May 1986, where the CEC activity limits for ^{137}Cs content of **370 Bq/kg** for baby food and **600 Bq/kg** for all other foodstuffs were introduced.

9.1.2 Finland

In the beginning of May 1986 the authorities decided to use the recommendations in the ICRP Publication 40 with regard to restricting the use of foodstuffs. A dose limit of effective dose to the critical group of **5 mSv** for the first year after the accident was set. In addition, a dose limit of **50 mSv** to single organs was set.

For ^{131}I, small children were considered to be the critical group, and the corresponding activity limit for milk and drinking water was set at **2000 Bq/ℓ**.

For ^{137}Cs the activity limits were based on the dose limit of **5 mSv**, and the corresponding activity limits were set at **1000 Bq/ℓ** for milk and **1000 Bq/kg** for meat.

9.1.3 Iceland

The fall-out levels in Iceland were all less than 100 Bq/m^2, and no activity limits for foodstuffs were set.

9.1.4 Norway

Dose limits for the exposure from intake of foodstuffs were set at **5 mSv/a** as the effective dose for the first year after the Chernobyl accident and **1 mSv/a** for the following years.

The activity limits were named ‘intervention limits’. The limits for the sum of activities of the radionuclides ^{134}Cs and ^{137}Cs were set at **370 Bq/kg** for milk and baby food, **600 Bq/kg** for other foodstuffs and **6000 Bq/kg** for reindeer, game and freshwater fish. For ^{131}I the limit was set at **1000 Bq/kg** for all foodstuffs.

9.1.5 Sweden

Since 1962 there had been established limits for activity content in imported foodstuffs. These limits were **2000 Bq/kg** for ^{131}I and **300 Bq/kg** for ^{137}Cs. After the Chernobyl accident the Swedish authorities set a dose limit of **5 mSv/a** for the first year after the accident and **1 mSv/a** for the following years for the exposure from intake of foodstuffs.

The activity limit for ^{137}Cs was set at **300 Bq/kg** for the most common foodstuffs. For foodstuffs which are consumed only in a limited amount, such as wild berries, mushrooms, reindeer and freshwater fish, the limit was set at **1500 Bq/kg**.

9.2 Common Nordic Levels for foodstuff restrictions

Under the auspices of the Nordic Council of Ministers the food control and radiation protection authorities have jointly developed so-called **Common Nordic Established Intervention Levels (CNEIL)** and **Common Nordic Temporary Emergency Levels (CNTEL)** for radionuclides in foodstuffs [16].

The CNEILs and the CNTELs are equal to the Codex values [10] and ten times the Codex values, respectively. These values correspond to dose limits of **1 mSv/a** and **5 mSv/a**, respectively. The CNTELs should be introduced automatically in the event of an accident and should be applied for only 30 days. Due to special circumstances of national character, the authorities in the Nordic countries can set activity limits between the CNEILs and the CNTELs.

If the Codex values were changed in the future, it is recommended that the CNEILs and the CNTELs be changed accordingly.

9.3 Evaluation of the Nordic Intervention Levels

Before a programme of intervention is initiated, the ICRP [6] recommends that it should be demonstrated, that the proposed intervention will be **justified**, i.e. do more good than harm, and furthermore that the form, scale, and duration of the intervention have been chosen so as to **optimise** the protection. The Commission recommends against the use of dose limits for deciding on the need for, or scope of, intervention. More precisely, the ICRP states that [6]:

> The dose limits recommended by the Commission are intended for use in the control of practices. The use of these dose limits or of **any other predetermined dose limits** as the basis for deciding on intervention might involve measures that would be out of all proportion to the benefit obtained and would then conflict with the principle of justification.

The ICRP recommends that the generically justified intervention level of averted dose for **any single food** would be 10 mSv. The IAEA recommends that the indicative optimised Intervention Level of averted dose for each of **seven main food categories** is 'about one to a few tens of mSv'.

The Nordic values for activity limits for foodstuffs have been based on dose limits. They have not emerged from a justification/optimisation process. In addition, they are used for the whole food basket, whereas both the ICRP and the IAEA recommend that optimisation be performed for a number of food categories.

An optimisation will not start from a dose level to derive activity levels for intervention, but rather the other way around. For each food category, the optimisation will give an Intervention Level directly and expressed in Bq/kg. The **implied dose** from a normal consumption of each food category can hereafter be compared with the Intervention Level of averted dose (see Appendix C).

As an example, the annual consumption of beef with a ^{137}Cs content of 30,000 Bq/kg determined from a generic optimisation (see Appendix C) would result in an annual committed effective dose of about 5 mSv. It will be in accordance with the recommendations from both the ICRP and the IAEA if the IL for restricting the consumption of beef is set at 30,000 Bq/kg (restrictions above 30,000 Bq/kg, no restrictions below 30,000 Bq/kg), because the averted collective dose ($>$ 5 man·mSv/kg) in monetary terms would exceed the cost of restricting the use of beef.

9.4 Generically optimised Nordic Intervention Levels

For Nordic conditions, generically optimised ILs for foodstuff restrictions, i.e. removal of foodstuffs from human consumption, and relocation have been derived with monetary costs and averted dose as the only parameters entering the optimisation. The monetary value of the unit collective dose has been assigned a value of 20,000 ECU·manSv^{-1}. The costs of the different foodstuff categories and of relocation are based on Danish economic conditions. These cost levels are, however, believed to be similar for the other Nordic countries, but this has to be verified in due course.

<u>Foodstuff restrictions</u>
For foodstuff restrictions, the food basket is divided into three main food categories:

- Milk, cheese, grain products and vegetables
- Pork, fish, poultry and eggs
- Beef and game

The division into three main groups is related to the price levels of the different foodstuffs, i.e. it is assumed that the price level is approximately the same within each main group. For the calculations made in this report the price levels for each of the three groups are 1 ECU/kg, 3 ECU/kg and 6 ECU/kg, respectively. The results of the optimisation are shown in Table 11.

Table 11. Calculated generically optimised ILs for cesium and iodine isotopes in 3 broad food categories.

Foodstuff	IL (Bq/kg)
Milk, cheese, grain products, vegetables	5,000
Pork, fish, poultry, eggs	15,000
Beef, game	30,000

The generic ILs in Table 11 for the specific food categories and the radionuclide group of cesium, iodine, ruthenium, etc. should be compared to the *sum of the activities* of these nuclides on the food category.

Due to higher dose factors per unit intake, the ILs for foodstuff restrictions would, for ^{90}Sr and α-emitters like ^{239}Pu and ^{241}Am, be a factor of 10 and 100 lower than the values in Table 11, respectively.

Relocation

The cost of relocation used to derive an optimised Intervention Level for relocation can cautiously be set at 200 ECU$\cdot$month$^{-1}\cdot$person^{-1} for Danish economic conditions. This value together with a value of the unit collective dose of 20,000 ECU$\cdot$Sv^{-1} will result in an optimised Intervention Level of:

$$IL_{rel} = 10 \text{ mSv}\cdot\text{month}^{-1}$$

If the dose accumulated per unit time in a contaminated area exceeds 10 mSv/month for normal living conditions, relocation should be introduced. Return to the area could accordingly take place when decay and weathering have reduced the dose level below the Intervention Level.

10 Summary and conclusions

Radiation protection criteria for dose reduction and intervention levels for protective measures following an accident have been developed by the international organisations for more than a decade. This process has been, and to some extent still is, very confusing because of the mix up with the system of radiological protection for practices. Dose levels for introducing countermeasures have been interpreted as doses **received** and not as doses **averted**; this might be interpreted as these levels were dose limits. The most striking and tragic example is the situation prevailing in the former Soviet Union after the Chernobyl accident.

In the early eighties the international organisations published guidance on Emergency Reference Levels for early countermeasures in the form of broad ranges of projected doses. For each countermeasure, lower and upper levels of dose were defined as references for the introduction of countermeasures. At dose levels below the lower level, no action was recommended. Above the upper level, action was almost certain to be recommended. This **two-tier system** of dose levels included doses equal to or a multiple of the dose limits recommended by the ICRP for practices. The recommendations did not include dose levels for the long-term countermeasures.

The recent development of intervention principles by the IAEA, ICRP and NEA are based on the justification and optimisation principles, namely that each countermeasure should be justified, i.e. do **more good than harm,** and the level of the protective measure should be optimised, i.e. do **the most good.** Each countermeasure should be optimised **separately**, independent of all other countermeasures.

The Nordic Intervention Levels for foodstuff restrictions have been based on **dose limits**, both for the Chernobyl accident and for future accidents. This is not in line with international recommendations from the ICRP and the IAEA because predetermined dose limits conflict with the principle of justification of intervention.

If Nordic Intervention Levels for foodstuff restrictions are based on the optimisation principle, with averted dose and monetary costs as the only parameters considered, the generically optimised ILs would be in the range of 5,000−30,000 Bq/kg for radionuclides with a low dose factor as ^{131}I and ^{137}Cs. For relocation, the generically optimised IL would be about 10 mSv/month. The assumption behind these figures is a monetary value of the unit collective dose of 20,000 ECU·manSv^{-1}.

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A Monetary value of the unit collective dose

In practice, it is not possible to avoid decisions involving a monetary value of the improvement of health risks in accident situations where remedial actions can reduce the risks imposed on a population or group of people. The decisions on risk improvement from resource-demanding measures should be made on the basis of optimising the resources, i.e. the largest improvement gained for a fixed amount of resources. Cost-benefit analysis, which is a well-established method in economic theory, has been shown to be a useful tool for decision making, although other and more extended methods exist.

There are no principal problems in the use of cost-benefit analysis as input to the decision making process, even if the improvement of the health risk is measured in monetary units. Several methods exist for the valuation of health risk reduction expressed in monetary terms. Two of these are briefly summarised here, namely the **Gross National Product Method** and the **Statistical Life Value Method.**

A.1 Gross National Product Method (Human Capital Approach)

The risk of radiation-induced fatal cancer, R, has recently been updated by the UNSCEAR. The value of the risk factor R for low radiation doses given at low dose rates is 0.05 Sv^{-1}. The loss of life expectancy, E, for a radiation-induced fatal cancer can be set at 15 years as an average value estimated from the **relative** and **absolute** risk models. The Gross National Product **(GNP)** per capita in Denmark is 25,000 $\mathrm{ECU \cdot a^{-1}}$ in 1991 prices.

The monetary value of the unit dose, α, can be calculated from these parameters with the assumption that a society is willing to pay, as a maximum, the value of the GNP per capita to **avoid** one year of lost life expectancy.

The monetary value of α can accordingly be expressed as:

$$\begin{aligned} \alpha &= R \cdot E \cdot GNP \qquad\qquad \text{(A.1)} \\ &= 0.05 \text{ cancer} \cdot \mathrm{Sv}^{-1} \cdot 15 \text{ a} \cdot \text{cancer}^{-1} \cdot 25,000 \text{ ECU} \cdot \mathrm{a}^{-1} \\ &= 20,000 \text{ ECU} \cdot \mathrm{Sv}^{-1} \end{aligned}$$

The radiation protection authorities in the Nordic countries have recommended an α-value of 20,000 $\mathrm{US\$ \cdot Sv^{-1}}$ before the change of the risk factor by UNSCEAR. After the revision of the radiation risk factors the Nordic radiation protection authorities have recommended an α-value of up to 100,000 US$ per man Sievert.

A.2 Statistical Life Value Method

From the so-called retrospective studies of the amount of money actually spent to save a human life, the value of a **statistical life** can be deduced. The literature on the subject is fairly large. A Danish study [15] evaluated some of this literature and the results of 9 independent studies on the value of a statistical life have been plotted on log-normal probability paper. These are shown in Figure A.1 below.

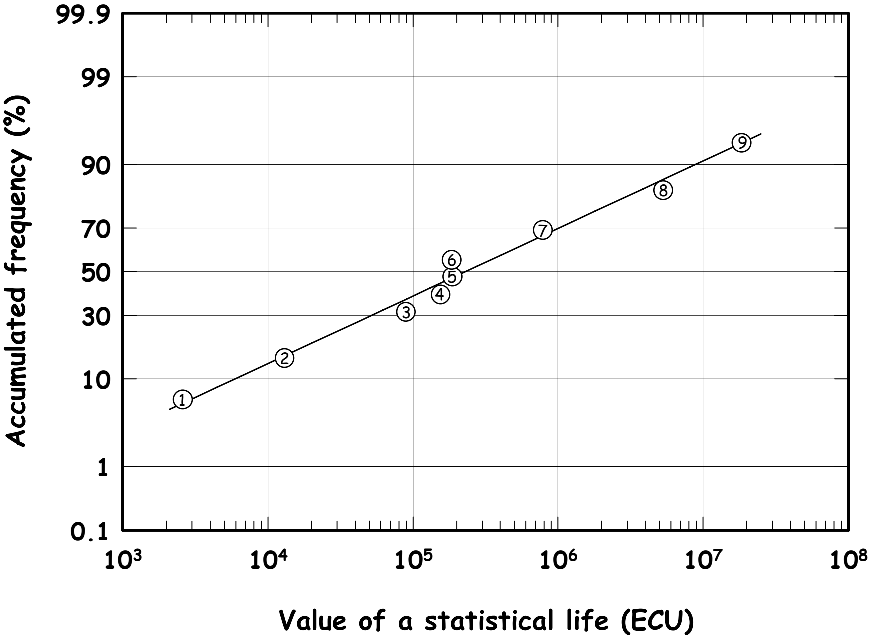

Figure 1. Different valuations of the price of a statistical human life.

The nine different values shown in the figure are based on the following sources:

(1) The amount of money spent by the British agricultural industry to avoid a fatal accident during field work

(2) Estimate from the British Road Laboratory

(3) The valuation of the authors [15]

(4) The valuation of the Danish Road Directorate in 1978

(5) The actual amount of money spent in the UK to avoid fatal traffic accidents

(6) The amount spent by the steel industry in the UK to avoid fatal accidents

(7) The result of an inquiry among health physicists

(8) The amount of money spent by the medical industry in the UK to avoid fatal accidents

(9) The valuation on the US Code of Federal Regulations (CFR) on the money spent on nuclear safety at the nuclear power plants in the US

The median value shown in the figure of about 200,000 ECU is close to the amount of money spent on traffic safety both in the UK and in Denmark. Correcting this figure for inflation gives a value of a statistical life in the order of 300,000 ECU in 1991 prices. If this value is used as an indicative **average** amount of money a western society is willing to pay for saving a statistical life, SL, the monetary value of α can be calculated to be:

$$\alpha = R \cdot SL = 0,05 \text{ life} \cdot \text{Sv}^{-1} \cdot 300,000 \text{ ECU} \cdot \text{life}^{-1} = 15,000 \text{ ECU} \cdot \text{Sv}^{-1} \quad \text{(A.2)}$$

B Principles for establishing Intervention Levels

The control of exposures following an accident can be achieved only by some form of intervention aimed at modifying the environment or restricting people's freedom of action or choice. Such intervention will impose some costs on society and may cause direct harm and disruption of life to some people. Consequently, it should not be taken lightly.

The purpose of intervention is to put potentially exposed individuals into a better position in the sense that lower overall risks are achieved at a reasonable cost in financial and social terms. While this objective is both clear and conceptually simple, the practical determination of what constitutes the most appropriate type and level of intervention in any particular circumstances is more complex. Because of the potential importance of political and social factors, there is, inevitably, much scope for differing outcomes; such differences should not be unexpected or surprising. However, these issues need to be addressed explicitly to achieve the objectives of the intervention.

Various decision-aiding techniques are available to assist judgements in such complex areas. None has, however, such compelling advantages as to recommend its universal application and much would depend on the problem being investigated. **Cost-benefit analysis** is one of the simpler and more readily understood techniques and, for this reason alone, has been used in [4] to **illustrate** a number of the more important issues in making decisions on intervention.

The problem of deciding on intervention levels can be conceptualized in simple cost-benefit terms, where the net benefit B is expressed as:

$$B = (Y_0 - Y_I) + B_c - X - R - A \tag{B.1}$$

where:

B is the **net benefit** achieved by the protective measure,

Y_0 is the cost equivalent of the radiation detriment if the protective measure **is not** taken,

Y_I is the cost equivalent of the remaining radiation detriment if the protective measure **is** carried out,

B_c is the cost equivalent of the reassurance benefit from the protective measure

X is the monetary cost of implementing the protective measure,

R is the cost equivalent of the risk introduced by the protective measure itself,

A is the cost equivalent of the anxiety and disruption caused by the protective measure.

It is evident from Equation (B.1) that intervention would be **justified** whenever the value of B was positive and that the **optimum** would be achieved when B was a maximum provided that the terms are defined broadly enough to encompass all the radiological protection factors. The **sole constraint** in this process is that intervention should be introduced at a level of individual dose below those at which serious deterministic health effects occur (see principle (3) of the IAEA guidance [4]); the **sole exception** to this generalization is the case in which such intervention would, in practice, worsen the situation.

In practice it is difficult to quantify, in monetary cost, all the terms of the equation, and subjective value judgements, similar to those in most social and economic decisions, would often need to be made. Equation (B.1), however, provides a conceptual framework for such judgements. Despite the broad international accord on the principles and objectives of intervention, differences are to be expected in their practical expression. These will result from differences in the weighting of the various terms in Eq. (B.1). The most important source of difference however, will, result from the weight given to factors of a non-radiological, socio-political, and enevitably less tangible nature. For example, there may be pressure by the public to introduce intervention in response to a perceived risk, even where the actual level of risk and the cost averting it would not, in itself, justify the intervention. Similarly, there may be pressure to maintain doses beneath existing dose limits or some other prescribed limits developed for a totally different purpose, despite its being wrong and possibly counterproductive.

Assuming that the cost terms B_c, R and A in Equation (B.1) are independent of the intervention level I, and that only the costs X and Y depend on I, then the maximum net benefit B occurs when:

$$\frac{\mathrm{d}X(I)}{\mathrm{d}I} + \frac{\mathrm{d}Y(I)}{\mathrm{d}I} = 0 \tag{B.2}$$

The cost equivalent of the remaining detriment if the protective measure **is** carried out, $Y(I)$, is given by:

$$Y(I) = \alpha \cdot S(I) \tag{B.3}$$

where α is the monetary value assigned to the unit collective dose. This parameter is discussed in more detail in Appendix A.

In the following, Equation (B.2) is further elaborated for the countermeasures **relocation/return** and **foodstuff restriction**. Illustrative numerical examples on intervention level settings for these two countermeasures are shown in Appendix B.

Relocation/Return

If relocation is applied to a group of people, N, who would each have experienced the same dose accumulated per unit time, $\dot{E}(t)$, for a time τ, during which individual doses now are zero, the cost terms in Eq. (B.1) can be rewritten as functions of relocation time τ:

$$Y_0 = \alpha \cdot N \cdot \int_0^\infty \dot{E}(t) \cdot \mathrm{d}t \tag{B.4}$$

$$Y_I(\tau) = \alpha \cdot N \cdot \int_\tau^\infty \dot{E}(t) \cdot \mathrm{d}t \tag{B.5}$$

$$\Delta Y(\tau) = Y_0 - Y_I(\tau) = \alpha \cdot N \cdot \int_0^\tau \dot{E}(t) \cdot \mathrm{d}t \tag{B.6}$$

$$X(\tau) = N \cdot (X_0 + a \cdot \tau) \tag{B.7}$$

where

a is the cost per unit time of relocation, e.g. cost for food and accommodation in the area of relocation,

X_0 is a fixed cost representing the transportation cost of a person and his belongings to and from the new location.

Relocation is then justified **only** if $B(\tau)$ in Equation (B.1) is positive at any given time τ. The optimum intervention level expressed as a **dose avertable per unit time** (which is different from an instantaneous dose rate) can be found by substituting the cost terms from Eqs. (B.4) - (B.7) into Eq. (B.1):

$$\frac{\mathrm{d}B(\tau)}{\mathrm{d}\tau} = \frac{\mathrm{d}\Delta Y(\tau)}{\mathrm{d}\tau} - \frac{\mathrm{d}X(\tau)}{\mathrm{d}\tau} \tag{B.8}$$

$$= \alpha \cdot N \cdot \dot{E}(\tau) - N \cdot a = 0$$

which leads to:

$$\dot{E}_{opt} = \frac{a}{\alpha} \tag{B.9}$$

It should be emphasized that the ratio a/α, and thus the optimum dose avertable per unit time by relocation (and its termination), will, in general, be much less sensitive to geographical location than either a or α alone, because both quantities are likely to be similarly correlated to national wealth.

Foodstuff restrictions

The rate at which the average individual effective dose is committed, $\dot{E}$, from the consumption of contaminated foodstuffs is proportional to the consumption rate, V, and the concentration of radionuclides in the food, $C(t)$:

$$\dot{E}(t) = C(t) \cdot V \cdot e(50) \tag{B.10}$$

where $e(50)$ is the committed effective dose per unit intake by ingestion of contaminated foodstuffs.

The cost per unit mass of a given foodstuff, b, and the consumption rate, V, of that foodstuff will give the cost of consumption of the foodstuff per unit time, a, as:

$$a = b \cdot V \tag{B.11}$$

which can be taken to be the cost of restricting the foodstuff per unit time. The cost of restricting foodstuffs over a time period, t, is therefore:

$$X(t) = a \cdot t = b \cdot V \cdot t \tag{B.12}$$

The benefit of the avertable dose from the restriction of the foodstuff over a time period, τ, is given as:

$$\Delta Y(\tau) = \int_0^\tau \dot{E}(t)\mathrm{d}t \tag{B.13}$$

and the net benefit, $B(\tau)$, of the restriction is:

$$B(\tau) = \Delta Y(\tau) - X(\tau) \tag{B.14}$$

The optimum Intervention Level can be found from:

$$
\begin{aligned}
\frac{\mathrm{d}B(\tau)}{\mathrm{d}\tau} &= \frac{\mathrm{d}\Delta Y(\tau)}{\mathrm{d}\tau} - \frac{\mathrm{d}X(\tau)}{\mathrm{d}\tau} \qquad (B.15)\\
&= \alpha \cdot \dot{E}(\tau) - b \cdot V\\
&= \alpha \cdot C(\tau) \cdot V \cdot e(50) - b \cdot V = 0
\end{aligned}
$$

which leads to the optimum value of the Intervention Level of avertable activity concentration:

$$
C_{opt} = \frac{b}{\alpha \cdot e(50)} \qquad (B.16)
$$

The optimum intervention concentration, C_{opt}, depends on the ratio b/α which will be less sensitive to geographical location than either b or α alone.

C Intervention Levels for late countermeasures

C.1 Relocation/return

The purpose of relocation is to prevent further exposure from radionuclides deposited on buildings and ground surfaces. The exposure pathways are external irradiation and inhalation of resuspended activity. These exposures have to be evaluated from measurements of the radiation fields and activity distribution and composition in the environment.

The cost of relocating an individual can be expressed as:

$$X_{rel}(t) = X_0 + a \cdot t \tag{C.1}$$

where X_0 is a fixed cost representing the transportation cost of a person and his belongings to the new location and a cost rate, a, representing the cost for food and accommodation and other cost rates such as lost income rate and deterioration rate of property.

The dose **averted** by relocation for a time τ, $E(\tau)$, is equivalent to an averted radiation detriment. The value of this detriment can be expressed as (see Section 2.2):

$$\Delta Y(\tau) = \alpha \cdot E(\tau) \tag{C.2}$$

where α is the monetary value assigned to the unit dose (see Appendix I). Relocation is **justified** if, at any time τ, the relocation cost per unit time is less than the cost of the radiation detriment **averted** per unit time.

The **Intervention Level (IL)** for introducing relocation (and its withdrawal) expressed as an optimum rate of dose averted per unit time, $\dot{E}_{opt}$, is, according to Section 2.2:

$$IL_{rel} = \dot{E}_{opt} = \frac{a}{\alpha} \tag{C.3}$$

The average cost rate for relocation in the Nordic countries can be set at $200 - 500$ ECU/month per person. Using a value range of α of $20{,}000 - 50{,}000$ ECU/Sv, relocation should be introduced in areas where the actual rate of dose accumulation will exceed:

$$\begin{aligned} IL_{rel} &= \frac{200 - 500 \text{ ECU} \cdot \text{month}^{-1}}{20{,}000 - 50{,}000 \text{ ECU} \cdot \text{Sv}^{-1}} = 4 - 25 \text{ mSv/month} \\ &\approx 10 \text{ mSv/month} \end{aligned} \tag{C.4}$$

If the time-averaged shielding factor for the given area is 0.2, the **Operational Intervention Level (OIL)** for relocation expressed as a free-air external dose rate will be:

$$OIL_{rel} = \frac{(4-25)/0.2}{24 \cdot 30} = 30 - 180\ \mu\text{Sv/h} \tag{C.5}$$

Therefore, in areas where the measured outdoor dose rate exceeds $30 - 180\ \mu$Sv/h, relocation should be implemented. When the outdoor dose rate due to decay and weathering drops below $30 - 180$ μSv/h, people can return to the area. If there is a significant inhalation exposure pathway from resuspended materiel, the averted dose should be calculated (projected) as the sum of the external and the committed effective inhalation dose and compared to the Intervention Level of $4 - 25$ mSv/month.

C.2 Foodstuff restriction

The purpose of imposing food restrictions is to prevent or reduce ingestion doses from contaminated foodstuffs. The costs of the remedial measures include the value of the lost produce and the costs of disposal and the institutional framework that will need to be set up and operated to effect the control.

According to Section 2.2 the **Intervention Level** for a **given foodstuff** expressed as the concentration of a **given radionuclide** will depend only on the cost of the foodstuff, b, and the value of the unit dose, α:

$$IL = C_{opt} = \frac{b}{\alpha \cdot e(50)} \tag{C.6}$$

In the following, calculations will be made for foodstuffs in a Danish "food basket". The total costs of the remedial measures will here be set equal to the **consumer prices**. The Danish "food basket" of approximately 500 kg/a per person is shown in Table C.1. The foodstuffs are categorised in seven price categories.

Table C.1. Food consumption rate and approximate cost levels.

Foodstuff		Consumption (kg/a)	Cost (ECU/kg)
Milk + cheese		173	1
Rye		29	
Wheat	Grain products	44	0.5
Oats		7	
Potatoes		73	
Cabbage		33	
Carrots	Vegetables	11	1
Apples, fruit		51	
Beef		18	6
Pork		37	3
Fish		11	4
Eggs		11	2

The optimised IL (C_{opt}) has been calculated for each of the 7 food categories for nuclides with a representative value of the dose factor $e(50)$ (dose per unit activity intake) of 10^{-8} Sv/Bq (Cs- and I-isotopes) and an α-value of 20,000 ECU/Sv. The effective doses committed in a year from the annual consumption shown in

Table C.1 has been calculated with the condition that **all** the foodstuffs are contaminated for the **whole year** to a level equal to the IL, in contrast to the CEC recommendations which assume that only 10% was contaminated for the whole year. The results are shown in Table C.2.

Table C.2. Calculated ILs foodstuff restriction for cesium and iodine isotopes in a Danish "food basket" and the resulting committed effective doses.

Foodstuff	Consumption (kg/a)	IL (Bq/kg)	E (mSv/a)
Milk + cheese	173	5,000	8.7
Grain Products	80	2,500	2.0
Vegetables	168	5,000	8.4
Beef	18	30,000	5.4
Pork	37	15,000	5.6
Fish	11	20,000	2.2
Eggs	11	10,000	1.1
Sum	498		33.4

Intervention Levels for foodstuffs established in this way, i.e. irrespective of the contamination of other foodstuffs and other exposure pathways, will make it necessary to ensure that the overall levels of doses do **not** approach the levels where deterministic effects might occur. In the above example, the optimum annual committed dose from ingestion of cesium or iodine isotopes is 33 mSv.

The corresponding ILs for ^{90}Sr and ^{239}Pu will be a factor 10 and 100 lower, respectively, due to higher dose factors.

If only 10% of the foodstuffs are contaminated up to the level of the ILs for the whole year, the annual committed effective dose will be a factor of 10 lower.

If the "food basket" is divided into 3 broad categories, the following values of the IL for Cs- and I-isotopes can be calculated for a Danish (Nordic) "food basket" to the values shown in Table C.3.

Table C.3. Calculated ILs for cesium and iodine isotopes in 3 broad food categories.

Foodstuff	IL (Bq/kg)
Milk, cheese, grain products, vegetables	5,000
Pork, fish, poultry, eggs	15,000
Beef, game	30,000

The annual committed effective doses from consumption of foodstuffs contaminated with ^{137}Cs up to these ILs for a whole year will be **33 mSv**, distributed with 20 mSv, 10 mSv, and 3 mSv on the categories milk, pork and beef, respectively.

The annual cost of the total "food basket" is according to Table C.1 equal to 666 ECU·a^{-1} giving an implicit α-value of 666/33 = 20 ECU·mSv^{-1} (Q.E.D.).

The ICRP recommends that the Intervention Level for restricting a single foodstuff is almost always justified at an effective dose committed in a year of 10 mSv. The IAEA recommends that the Intervention Levels for restricting foodstuffs should be in the range of **one to a few tens of mSv** separately for **each** of seven food categories: dairy products, meats, vegetables, grain, fruit, drinking water, and beverages. The intervention levels in Tables C.2 and C.3 are therefore in good agreement with both the ICRP and the IAEA recommendations.

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A radiation protection philosophy for exposure situations following an accident has been developed by international organisations such as the ICRP, IAEA, NEA/OECD, FAO/WHO, and the CEC during the last decade. After the Chernobyl accident, the application of radiation protection principles for intervention situations such as exposure from accidental contamination or radon in dwellings were further developed and this work is still in progress. The present intervention policy recommended by the international organisations as well as by the Nordic radiation protection authorities is reviewed. The Nordic Intervention levels for foodstuff restrictions, both for the Chernobyl and post-Chernobyl periods, have been based on dose limits and they are therefore in conflict with international intervention policy. Illustrative examples on intervention level setting for relocation and foodstuff restrictions are derived for Nordic conditions from the optimisation principle recommended by the international organisations. Optimised Generic Intervention Levels have been determined to be about 10 mSv-month for relocation/return and 5,000 - 30,000 Bq kg for restrictions on various foodstuffs contaminated with ^{137}Cs and ^{131}I.

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